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SOIL ORGANIC CARBON STOCKS UNDER DIFFERENT FOREST TYPES OF HIMALAYAN MOIST TEMPERATE FORESTS IN SHIMLA DISTRICT, HIMACHAL PRADESH, INDIA

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ABSTRACT

The current study was conducted in Shimla district which forms a part of southern Himachal Pradesh. The district lies between the longitudes 76°59'22" and 78°18'40" East and latitudes 30°45'48" and 31° 43' 0" North. Composite soil samples (0-15 cm and 15-30cm) from each sample plot in different forests were collected during autumn season, three replicates of each composite sample were made. They were air dried, crushed and passed through 2 mm sieve and stored in cloth bags. Different parameters such as bulk density, organic carbon (%) and SOC (t/ha) in the soil were estimated. Results revealed that, in general, there was a significant decrease in bulk density of soil along the elevation in both the depths of the soil. Further, bulk density of soil in different forests was significantly lower at depth 0-15 cm as compared to 15-30 cm depth of soil. Soil organic carbon was significantly influenced by elevation and soil depth. The result reveals that soil organic carbon (%) declined significantly with ascending elevation. Soil carbon density (t/ ha) is significantly influenced by the average effects of latitudinal ranges and soil depth. Soil carbon density (t/ ha) declined significantly with ascending elevation, here in soil depths, maximum soil carbon density was recorded in 0-15 cm soil. Maximum soil carbon density (27.89 t/ha) was recorded in Ban Oak forests at E_1 at the depth of 0-15 cm.

KEYWORDS: Bulk Density, Soil Organic Carbon, Soil Depth and Moist Temperate Forests

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Original Article

INTRODUCTION

Soil organic carbon is considered to be one of the largest carbon reservoirs of the terrestrial ecosystems and also plays an important role in the global carbon cycle (Batjes, 1996). Forests act as one of the largest carbon sinks and helps to control atmospheric CO_2 concentrations (Zhou *et al, 2006*). Forest soil contains a globally significant amount of carbon (C), approximately half of earth's terrestrial carbon is in forests (1146×1015 g), and of this amount, about two- thirds is retained in soil pools (Dixon *et al,* 1994). Temperate forest ecosystems contain a significant amount of soil organic carbon (C), both globally and regionally (Rasmussen *et al,*).

It has been estimated that present carbon stock in the world's forests is 861 ± 66 Pg C, of which 383 ± 30 Pg (44%) is in the soil to a depth of 1 meter. Temperate forests' contribution to world forest carbon stock is 14 % (119 ± 6 page) (Pan *et al,*). Based on average global or regional soil carbon densities estimated in Indian forest soils, it has been calculated that our soil organic carbon pool ranges from 5.4 to 6.7 Pg (Dadhwal *et al,*). Soil organic carbon is normally estimated to a depth of 0-30 cm since (Ravindranath and Ostwald 2008). Thus the quantity of SOC in the 0-30 cm layer is about twice the amount of carbon in atmospheric carbon dioxide (CO2) and three times

that in global above ground vegetation (Powlson *et al*, 2011). It is estimated that the global stock of SOC to a depth of 30 cm is 684-724 Pg (Batjes, 1996).

A small change in soil carbon results in a large change in atmospheric concentrations. It is essential to study the mechanisms and changes of forest SOC to better understand and mitigate climate change (Fang *et al*, 1996). Mountainous cold-temperate areas have high SOC content, but large spatial variability, due to variable climate and vegetation (Li *et al*, 2010). This spatial variability has made it difficult to predict the spatial distribution of SOC in forest soils. Various studies have reported the influence of topography (Yoo *et al.* 2006), climatic conditions (Davidson and Janssens 2006), soil composition (Davidson and Janssens 2000), litter quality and its decomposition rate (Yang *et al.* 2005) and species composition or vegetation type (Schulp et al. 2008) on the spatial distribution of SOC. The Himalayas are among the youngest mountain ranges on the planet and consists mostly of sedimentary and metamorphic rocks. In India, the Himalaya occupies 16.2% of the total geographical area and spans over 12 states of the country. The Himalayas in India are categorized into Northern Himalaya, Western Himalaya, Central Himalaya and North-eastern Himalaya (Nautiyal *et al.* 2005). Hence the present study was aimed to estimate the SOC stock assessment in nine different forest types widely distributed in the Shimla district of Himachal Pradesh.

MATERIALS AND METHODS

Location of the Site

Shimla district forms a part of southern Himachal Pradesh. The district lies between the longitudes 76°59'22" and 78°18'40" East and latitudes 30°45'48" and 31° 43' 0" North. Mostly the terrain is rough and the topography of the district is characterized by high mountains, river basins and, deep and narrow valleys. The elevation of the district ranges from 300-6,000 meters above mean sea level The district has an area of 5,131 km^2 out of a total area of 55,673 km^2 of Himachal Pradesh. Various Himalayan temperate forests in Shimla district are Ban oak forest ($12/c_1a$), Moru oak forest ($12/c_1b$), Moist deodar forest ($12/c_1c$), Western mixed coniferous forest($12/c_1d$), Moist temperate deciduous forest($12/c_1e$), Low level blue pine forest($12/c_1f$), Kharsu oak forest ($12/c_2a$), Upper oak/fir forest($12/c_2b$) and Moist temperate deciduous forest($12/c_2c$).

Table 1: Types of Himalayan Moist Temperate Forest in Shimla District of Himachal Pradesh, Their Elevation Ranges and Delineation of E1, E2 and E_3 in each of them for their Detailed Study

Type of Himalayan Moist Temperate Forest	Type (according to Champion & Seth, 1968)	Elevation		
		E_1	E_2	E_3
Ban Oak forests	(12/c1a)	700 -1300	1300-1900	1900-2500
Moru Oak forests	(12/c1b)	1800-2300	2300-2800	2800-3300
Deodar forests	(12/c1c)	900-1800	1800-2700	2700-3600
Western mixed coniferous forests	(12/c1d)	1200-2100	2100-3000	3000-3900
Moist temperate lower deciduous forests	(12/c1e)	500-1300	1300-2000	2000-2700
Kail forests	(12/c1f)	1400-2100	2100-2800	2800-3600
Kharsu forests	(12/C2a)	2300-2800	2800-3200	3200-3600
Upper Oak-Fir forests	(12/c2b)	2100-2600	2600-3100	3100-3500
Moist temperate upper deciduous forests	(12/c2c)	1700-2300	2300-2900	2900-3500

Soil Analysis

Composite soil samples (0-30cm) from each sample plot in different forests were collected during autumn season, three replicates of each composite sample were made. They were air dried, crushed and passed through 2 mm sieve and stored in cloth bags. Bulk density of each soil sample was determined by following Specific gravity method given by Singh, (1980) and Organic carbon in the soil was estimated by the method given by Walkley and Black (1934). While soil organic carbon was calculated by using the formula given by FAO. The variations in SOC stock among different forest types and soil depths (0-15 and 15-30 cm) were examined with analysis of variance (ANOVAs).

RESULTS AND DISCUSSIONS

Results in the Table 1 reveal that, in general, there was a significant decrease in bulk density of soil along the elevation in both the depths of the soil. Further, bulk density of soil in different forests was significantly lower at depth 0-15 cm as compared to 15-30 cm depth of soil. Comparing bulk density of soil in different forests at different elevations it was evident that in Ban Oak and Moru Oak forests the bulk density of the soil was higher as compared to other forests. Highest bulk density (1.32 g/cm^3) was recorded in soil depth of 15-30 cm at E_1 in Ban Oak forest, which was followed by 1.20 g/cm^3 in 15-30 cm deep soil in Moru Oak forests at E_1, 1.14 g/cm^3 in 15-30 cm deep soil in Western mixed coniferous forests, 1.13 g/cm^3 in 15-30 cm deep soil in Moist temperate upper deciduous forests at E_1 and 1.12 g/cm^3 in 0-15 cm deep soil of Ban Oak forests at E_1. Minimum value (0.82 g/cm^3) of bulk density was recorded at E_3 in 0-15 cm depth of soil in Western mixed coniferous forests followed by 0.83 g/cm^3 in 0-15 cm depth of soil in Kharsu Oak forests and moist temperate upper deciduous forests at elevation E_3. Interaction effects of soil depth and elevation on bulk density of soil was statistically significant.

Table 2: Change in Soil Bulk Density (g/cm^3) along Elevation in Different Forests

Forest Types (T)	Soil Bulk Density (g/cm^3) at Two Depths (D)							
	0-15 cm				15-30 cm			
	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean
Ban Oak forests	1.12	1.07	0.98	**1.06**	1.32	1.09	1.04	**1.15**
Moru Oak forests	1.10	0.98	0.92	**1.00**	1.20	1.08	1.01	**1.10**
Deodar forests	0.98	0.93	0.93	**0.95**	1.04	1.01	0.97	**1.01**
Western mixed coniferous forests	1.11	0.96	0.82	**0.96**	1.14	1.00	0.94	**1.03**
Moist temperate lower deciduous forests	0.92	0.90	0.85	**0.89**	1.11	0.97	0.92	**1.00**
Kail forests	0.90	0.92	0.86	**0.89**	0.97	0.94	0.90	**0.94**
Kharsu Oak forests	0.89	0.92	0.83	**0.88**	1.01	0.94	0.89	**0.95**
Upper Oak-Fir forests	1.02	0.89	0.90	**0.94**	1.07	0.93	0.91	**0.97**
Moist temperate upper deciduous forests	0.92	0.90	0.83	**0.88**	1.13	1.04	0.88	**1.02**
Mean	**0.92**	**0.90**	**0.83**		**1.13**	**1.04**	**0.88**	
$CD_{0.05}$	**0.42**	**0.13**	**0.14**		**0.27**	**0.20**	**0.31**	

Where: E_1, E_2 and E_3 are the respective elevation zones of different forests.

Maximum bulk density was recorded in ban oak forest 1.32 g/cm^3 at 15-30 cm. The variation in the bulk density under different treatments can be owed to their varying rate of leaf- litter deposition. Above results showed maximum bulk density at the depth of 15-30 cm at E_1. Bulk density decreases with an increase in depth. The bulk density of the soil reflects the level of compaction and amount of pore space in the soil. Bulk density was dependent on available macronutrients and micronutrients in the soil. It decreases as the total macronutrient or total micronutrient contents in the

soil increases. Similar results were recorded by Kanagaraj *et al.* (2017) who reported that bulk density was negatively correlated to the altitude, it decreases as altitude increases. These findings are in agreement with the findings of Cihacek and Ulmer (1998).

Table 3: Change in Soil Organic Carbon (SOC %) along Elevation in Different Forests

Forest Type	Soil Organic Carbon (%)at Two Depths (D)							
	0-15 cm				15-30 cm			
	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean
Ban Oak forests	1.66	1.32	1.29	**1.42**	1.41	1.22	1.04	**1.22**
Moru Oak forests	1.64	1.04	1.01	**1.23**	1.09	1.06	0.99	**1.05**
Deodar forests	1.19	1.25	1.13	**1.19**	1.23	1.16	1.08	**1.16**
Western mixed coniferous forests	1.54	1.31	1.24	**1.36**	0.98	0.96	0.96	**0.97**
Moist temperate lower deciduous forests	1.23	1.11	1.07	**1.14**	0.96	0.96	0.92	**0.95**
Kail forests	1.58	1.23	1.19	**1.33**	1.08	0.94	0.93	**0.98**
Kharsu Oak forests	1.31	1.14	1.09	**1.18**	1.17	1.08	1.02	**1.09**
Upper Oak-Fir forests	1.44	1.06	0.95	**1.15**	1.06	0.93	0.89	**0.96**
Moist temperate upper deciduous forests	1.46	1.21	1.16	**1.28**	1.10	1.15	1.08	**1.11**
Mean	**1.45**	**1.19**	**1.13**		**1.12**	**1.05**	**0.99**	
$CD_{0.05}$	**0.26**	**0.21**	**0.43**		**0.36**	**0.59**	**0.18**	

Where: E_1, E_2 and E_3 are the respective elevation zones of different forests.

A perusal of the data presented in the Table 3 reveals that soil organic carbon was significantly influenced by elevation and soil depth. The result reveals that soil organic carbon (%) declined significantly with ascending elevation. Whereas, related to soil organic carbon decreased significantly with an increase in depth. Significantly highest soil organic carbon (1.66 %) was recorded in the Ban oak forest at E_1 at 0-15 cm depth followed by Moru Oak forest at E_1 (1.64 %) at 0-15 cm depth. While lowest soil organic carbon was recorded in Upper Oak-Fir forests (0.89 %) at 15-30 cm depth at E_3 elevation. Comparing different forests for soil organic carbon in 0-15 cm depth or 15-30 cm depth of the soil, it was recorded that it decreased in the order: Ban Oak forests > Moru Oak forests > Kail forests > Western mixed coniferous forests > Moist temperate upper deciduous forests > Upper Oak-Fir forests > chose forests > Moist temperate lower deciduous forests > Deodar forests.

From above table, soil organic was found to be maximum (1.66 %) in Ban Oak forest, followed by Moru Oak Forest at 0-15 cm at E_1. The higher soil organic carbon (SOC) in oak forest and oak mixed forest could be due to closed canopied forest resulting in higher inputs of litter which enriches SOC (Anuradha, 2014). Results are comparable with the findings of Devi B (2011), who recorded maximum bulk density (2.96 %) under oak and pine forest. There was gradual decline in the availability of % OC towards lower soil depths and with increase in altitude in all forests types. Higher organic carbon accumulation in surface soil than sub-surface layers could be attributed to higher amount of litter accumulation on surface. These results are in accordance with the findings of Banerjee and Badola (1980). Increase in the SOC can be due to the change in the climatic condition at higher elevation as well the decrease in OM accumulation along the elevation gradients (Kanagaraj *et al.*, 2017).

Table 4: Soil Organic Carbon Stock under Different Forest Types at Different Elevations

Forest Types (T)	Soil Organic Carbon Stock (t/ha) at Two Depths (D)							
	0-15 cm				15-30 cm			
	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean
Ban Oak forests	27.89	21.19	18.96	22.68	27.52	19.95	16.22	21.36
Moru Oak forests	27.06	15.29	13.94	18.76	19.62	17.17	15.00	17.26
Deodar forests	17.49	17.44	15.76	16.90	19.19	17.57	15.71	17.49
Western mixed coniferous forests	25.64	18.86	15.25	19.92	16.76	14.40	13.54	14.90
Moist temperate lower deciduous forests	16.97	14.99	13.64	15.20	15.98	13.97	12.70	14.22
Kail forests	21.33	16.97	15.35	17.89	15.71	13.25	12.56	13.84
Kharsu Oak forests	17.49	15.73	13.57	15.60	17.73	15.23	13.62	15.52
Upper Oak-Fir forests	22.03	14.15	12.83	16.34	17.01	12.97	12.15	14.05
Moist temperate upper deciduous forests	20.15	16.34	14.44	16.98	18.65	17.94	14.26	16.95
Mean	**21.78**	**16.77**	**14.86**		**18.73**	**15.83**	**13.97**	
$CD_{0.05}$	**1.06**	**0.45**	**0.53**		**0.98**	**0.85**	**0.78**	

Where: E_1, E_2 and E_3 are the respective elevation zones of different forests.

A perusal of the data presented in the Table 4 reveals that soil carbon density (t/ ha) is significantly influenced by the average effects of altitudinal ranges and soil depth. The data revealed that the soil carbon density (t/ ha) declined significantly with ascending elevation, here in soil depths, maximum soil carbon density was recorded in 0-15 cm soil. Maximum soil carbon density (27.89 t/ha) was recorded in Ban Oak forests at E_1 at the depth of 0-15 cm, followed by 27.52 t/ha of soil density at 15-30 cm depth at E_1 in Ban Oak forests which was statistically at par with Moru Oak forests (27.06 t/ha) at 0-15 cm depth at E_1 and Western mixed coniferous forests (25.64 t/ha) at 0-15 cm at E_1. Lowest soil carbon density (12.15 t/ha) was recorded at E_3 in Upper Oak-Fir forests at 15-30 cm depth.

Maximum SOC recorded at 0-15 cm in Ban Oak forests at E_1. SOC showed decreasing trend with increasing altitude and soil layer. Soil organic carbon (SOC) depends upon various biotic and abiotic factors such as microclimate, faunal diversity, land use and management. Leaf litter and root litter input play a major role in forest soil. The upper layer remains in dynamic equilibrium with biological and anthropological activities and is generally richer in C than the lower layers (Kanagaraj *et al.*, 2017). Similar results were also reported earlier by Shrestha *et al.* (2004) in mountain watershed of Nepal.

CONCLUSIONS

Increase in the SOC is due to the change in the climatic condition at higher elevation as well the decrease in OM accumulation along the elevation gradients. (Kanagaraj *et al.*, 2017). The relatively large mean SOC density in the top layers could be attributed to higher OM inputs by litter fall causing higher accumulation of SOC in the upper layer of the mineral soil. The increase in SOC density with altitudinal zone was largely due to increase in SOC concentration with altitude resulting from higher OM inputs from above- and belowground biomass, slow decomposition due to low temperature (Trumbore *et al.*, 1996) and more translocation of OC into deeper layer. The presence of non-volcanic andosolic soils in the upper altitudinal zones might have stabilized SOC by forming complexes probably promoted by the soil andic and spodic properties (Bäumler *et al.*, 2005). The increase in SOC density with increasing altitude of the altitudinal zone is largely due to increase in SOC concentration (Griffiths *et al.*, 2009). It was also found that the altitude

factor affects the vertical distribution of SOC density in the profiles by influencing climatic factors like temperature and precipitation. A strong correlation of SOC with mean annual temperature and precipitation, and clay content was also reported by Jobbágy and Jackson (2000).

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